Final Report:

Concentrations of Selenium in Eared Grebes from the Great Salt Lake, Utah

Michael R. Conover, Wildland Resources, Utah State University, Logan, UT 84322-5230

John Luft, Utah Division of Wildlife Resources, 1594 W. North Temple, Salt Lake City, UT 84114

Clay Perschon, Utah Division of Wildlife Resources, 1594 W. North Temple, Salt lake City, UT 84114

Abstract

We examined selenium and mercury concentrations in eared grebes (*Podiceps nigricollis*) that spent the fall of 2006 on the Great Salt Lake, Utah. Food items in the birds' esophagus consisted primarily of brine shrimp. Selenium concentrations in livers varied based on when the grebes were collected (lower in September [mean ± SE = 9.4 ± 0.7 µg/g on a dry weight basis] than November [14.5 ± 1.4 µg/g]), where the birds were collected (Antelope Island = 8.6 ± 0.5 µg/g and Stansbury Island = 15.2 ± 1.4 µg/g), and the grebe's age (juveniles 8.5 ± 1.5 µg/g and adults = 15.8 ± 1.3 µg/g), but not by sex. In contrast, selenium concentrations in blood differed only by collection site (Antelope Island = 16.8 ± 2.3 and Stansbury Island = 25.4 ± 3.0 µg/g). Mercury concentration in the blood of grebes varied by when the grebes were collected (September = 5.6 ± 0.5 µg/g and November = 8.4 ± 1.2 µg/g), where the birds were collected (Antelope Island = 4.3 ± 0.5 and Stansbury Island = 10.1 ± 2.6 µg/g), and the grebe's age (juveniles = 5.5 ± 0.8 and adults 8.4 ± 1.0 µg/g), but not by sex. Selenium concentrations in blood were correlated with selenium concentrations in the liver and mercury concentrations in both blood and liver. Mercury levels in blood and liver were also correlated. Liver mass, pancreas mass, and spleen mass were not related to either selenium or mercury concentrations. Body mass of grebes increased dramatically from September (381 ± 14 g) to November (591 ± 11 g). Body mass was either not correlated with selenium or mercury concentrations, or the relationship was positive. These results suggest that high mercury and selenium levels were not preventing grebes for increasing or maintaining mass.

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Introduction

Selenium is a naturally occurring trace element, and small quantities of it are essential for animal health. However, it becomes toxic at higher concentrations. Elevated concentrations of selenium have been shown, both in captive and free-ranging birds, to cause reduced egg hatchability, embryonic defects, and lower survival rates of chicks and adults (Ohlendorf et al.1989, Ohlendorf 2003). For example, several avian species foraging in California's Kesterson Reservoir accumulated high concentrations of selenium in their tissues that impaired their reproductive ability and caused mortality of adult birds (Ohlendorf et al. 1989; Ohlendorf 2002, 2003).

The Great Salt Lake (GSL) in Utah is an important habitat for many avian species. About half of North America's eared grebes (*Podiceps nigricollis*) spend the fall on the GSL eating brine shrimp and accumulating enough nutrients to fly to their wintering grounds in Mexico and California. Hence, there is a need to ensure that selenium concentrations in the GSL do not reach levels that would impair the health or reproduction of the birds that depend upon the GSL. For this reason, the Utah Division of Water Quality wants to establish a water standard for selenium in the GSL. To aid this effort, we measured selenium concentrations in eared grebes in September (soon after they arrived on the GSL) and then again in late November before they migrate from the GSL. Because of the possible interactions between selenium and mercury that may affect bioaccumulation and effects, we also measured concentrations of mercury in grebe blood and livers.

This study was designed to answer the following specific questions.

1. What are selenium and mercury concentrations in blood and liver of eared grebes collected on the GSL?
2. Do eared grebes accumulate selenium and mercury while on the GSL?
3. Do selenium and mercury concentrations vary based on where the grebes were collected on the GSL or the age or sex of the birds?
4. Are selenium and mercury concentrations in blood and liver correlated?
5. Do selenium or mercury concentrations affect body condition of eared grebes on the GSL?

Methods

Collection of grebes. During September and November 2006, we collected eared grebes located in the GSL off Antelope Island and Stansbury Island (Figure 1). During these months, the grebes are flightless, and we used a shotgun and steel shot to collect them as they swam on the water surface. We collected 30 grebes during each month with an equal number (15) being collected at each site.

We immediately used a syringe to collect at least 1 mL of blood from the thoracic cavity. The blood was kept in the syringe and frozen. Within 12 hours of when the birds were collected, we collected all food from the bird's esophagus and obtained a liver sample. The liver sample was placed in a Whirl-Pak® bag and frozen. Esophagus samples were weighed (wet weight) and were stored in 95% alcohol. We determined the birds' body mass, aged them by eye color (Cullen et al. 1999), and determined their sex by gonadal inspection. We weighed each bird's liver, spleen, and pancreas. Food in the esophagus was sorted by species, and numbers of each species were counted because food items were too small and scarce to accurately weigh.

Selenium and mercury analysis. Blood and liver samples from some grebes were sent to Laboratory and Environmental Testing Incorporated (LET), Columbia, Missouri, for selenium and mercury analysis. LET analyzed the tissue for total selenium using hydride generation atomic absorption spectrometry and mercury using cold vapor atomic absorption spectrometry, with a target reporting limit of 0.2 µg/g. Selenium and mercury concentrations are reported on a dry-weight basis. Quality control of chemical analyses was conducted using one or more method blanks, matrix spikes, matrix spike duplicates, and reference samples for each sample batch (CH2M HILL 2006).

Statistical analyses. To determine if the data were normally distributed, I examined data on the grebes collected during September separately from the grebes collected during November. For both datasets, selenium and mercury concentrations were normally distributed based on the D'Agostino-Pearson Omnibus K^2 normality test.

Analyses of Variance (ANOVAs) were used to determine the effect of collection date (September versus November), collection site (Antelope Island versus Stansbury Island), age of bird (juveniles versus adults), and sex on selenium concentrations in blood and liver. We did not determine the mercury concentrations in liver samples from juvenile birds. Because of this, there was an insufficient sample size to conduct an ANOVA on mercury concentrations in livers. We did, however, conduct an ANOVA to examine the effect of collection date, collection site, and sex on mercury concentrations in blood samples.

Regression tests were conducted to compare selenium and mercury concentration in an individual grebe's blood and liver. Selenium and mercury concentrations were also regressed with body mass, liver mass, spleen mass, and pancreas mass. Fat mass was not used because grebes fast before migrating from the GSL; therefore, it is not a reliable predictor of body condition of grebes. Because grebe mass varies by age and sex, we first conducted regression tests on all bird combined, and then separately analyzed juvenile males, adult males, juvenile females and adult females using only those birds collected in November. In all tests, results were considered significant if $P < 0.05$.

Results

Food analyses.–All grebes had a mass of feather fragments and brine shrimp (*Artemia* spp.) cysts in their gizzard; individual food items in the gizzard could not be identified. Hence, food analyses were limited to items in the birds' esophagus. Collected grebes had so few food items in their esophagus that food items were individually counted because weights were meaningless. During September, grebes were feeding primarily on adult brine shrimp and adult brine flies. During November, food items in the grebes contained almost entirely adult brine shrimp (Appendix 1).

Selenium and mercury analyses.– Selenium concentrations in livers varied based on when the grebes were collected (lower in September [mean $\pm$ SE = 9.4 $\pm$ 0.7 µg/g on a dry-weight basis] than November [14.5 $\pm$ 1.4 µg/g]), where the birds were collected (Antelope Island = 8.6 $\pm$ 0.5 and Stansbury Island = 15.2 $\pm$ 1.4 µg/g), and the grebe's age (juveniles = 8.5 $\pm$ 1.5 and adults = 15.8 $\pm$ 1.3 µg/g), but not by sex (Tables 1-3). In contrast, selenium concentrations in blood differed only by collection site (Antelope Island = 16.8 $\pm$ 2.3 and Stansbury Island = 25.4 $\pm$ 3.0 µg/g dry weight). Mercury concentration in the blood of grebes varied by when the grebes were collected (September = 5.6 $\pm$ 0.5 µg/g and November = 8.4 $\pm$ 1.2), where the birds were collected (Antelope Island = 4.3 $\pm$ 0.5 µg/g and Stansbury Island = 10.1 $\pm$ 2.6), and the grebe's age (juveniles = 5.5 $\pm$ 0.8 µg/g and adults = 8.4 $\pm$ 1.0), but not by sex (Tables 1-3).

When all birds were combined, selenium concentrations in blood and liver and mercury concentrations in blood and liver were all positively correlated with each other (Table 4). When juvenile males, adult males, juvenile females, and adult females collected in November were analyzed separately (Tables 5 and 6), selenium concentrations in blood were correlated with selenium concentrations in liver in all sex-age groups. In males, selenium concentrations in the liver and blood were correlated with mercury levels in blood but not mercury levels in livers (Table 5). In females, selenium concentrations were not correlated with mercury concentrations (Table 6), but sample sizes for females were so small that the probability of a Type II error was high. This was also true for comparisons involving mercury concentrations if the livers of males.

When all grebes were combined, there was a positive correlation between body mass and selenium concentrations in blood and liver and mercury concentrations in liver (Table 4). When only grebes collected in November were considered and each age-sex group was analyzed separately, body mass was not correlated with selenium or mercury concentrations with two exception — mass of adult males was correlated with selenium concentrations in the liver (r^2 = 0.36) and mass of juvenile females was correlated with mercury concentrations in the blood (r^2 = 1.0). In both cases, the relationship was positive (Tables 5 and 6). Liver mass, pancreas mass, and spleen mass were not correlated with either selenium or mercury concentrations (Table 4).

Discussion

In eared grebes, we found that selenium concentrations in livers ranged from 5 to 28 µg/g. In California gulls (*Larus* californicus) that we collected from the GSL during the spring, selenium concentrations ranged from 4 to 14 µg/g (Conover et al. 2007). In other species, mean background levels of selenium have been reported to be less than 10 µg/g in livers (USDI 1998, Ohlendorf 2003). Our results indicate that selenium concentrations in liver samples were generally consistent with background concentrations for grebes collected in September. For eared grebes captured in November, however, all of those from Stansbury Island (range 17.4 to 28.4 µg/g) had selenium concentrations in livers that exceeded the 10 µg/g threshold that is considered to be the background level in liver tissue (Ohlendorf 2003). Grebes captured during November near Antelope Island had selenium concentrations (range 6.7 to 8.7 µg/g) consistent with background levels.

Among grebes collected during November, selenium concentrations in blood ranged from 1 to18 µg/g from birds collected near Antelope Island and 22 to 55 µg/g from birds collected near Stansbury Island. In California gulls that we collected during their breeding season on the GSL, selenium concentrations in blood ranged from 5 to 46 µg/g (Conover et al. 2007). These concentrations were higher than we expected given the concentrations found in livers. Selenium concentrations in the blood of predatory terrestrial birds (kestrel [*Falco sparverius*], red-tailed hawk [*Buteo jamaicensis*], northern harrier [*Circus cyaneus*], barn owl [*Tyto alba*], and loggerhead shrike [*Lanius ludovicianus*]) from a contaminated grassland in California ranged from 1 to 38 µg/g dry weight (Santolo and Yamamoto 1999). Selenium concentrations in whole blood above 2 µg/g dry weight are considered to exceed normal background, and 5 µg/g dry weight is considered a provisional threshold indicating that further study is warranted (USDI 1998).

We do not know why grebes collected around Stansbury Island during November had higher concentrations of selenium than those from around Antelope Island. However, during November, Stansbury Island grebes also had much higher mercury concentrations in their blood (range = 11.5 to 18 µg/g) than Antelope Island grebes (range = 2.5 to 4.7 µg/g). Selenium and mercury can interact to form a stable complex so that selenium can provide adult birds some protection from mercury toxicity (Ohlendorf 2003, Wiener et al. 2003). This interaction between mercury and selenium may cause an enhanced accumulation and retention of both chemicals in birds (Furness and Rainbow 1990, Scheuhammer et al. 1998, Spalding et al. 2000, Henny et al. 2002). Differences in blood and liver concentrations of selenium may result from faster selenium initial elimination in liver than blood and to the binding of selenium to inorganic mercury creating an inert mercury-selenium protein (Wayland et al. 2001). In wading birds, selenium and mercury concentrations were positively correlated in the blood, but not in liver or kidney tissues (Goede and Wolterbeek 1994). When we analyzed juvenile males, adult males, juvenile females, and adult females separately and used only those birds collected in November, selenium concentrations in both blood and liver were correlated with mercury concentrations in blood for males but not females. However, sample sizes were small for females and this increased the likelihood of a Type II error. Still, we discovered among female grebes a positive correlation between selenium concentrations and blood mercury levels.

Although the few studies of selenium-mercury interaction in birds used various forms of selenium and mercury (some not using environmentally relevant forms), they do provide approximations of potential effects. In a study by Heinz and Hoffman (1998) using mercury as methylmercury chloride and seleno-DL-methionine, captive female mallards (*Anas platyrhynchos*) fed a diet containing both 10 µg Se/g of feed and 10 µg Hg/g had a selenium concentration in the liver 1.5 times higher than females fed a diet containing just selenium (10 µg Se/g). In the same experiment, male mallards fed the selenium and mercury combination diet had almost 12 times the selenium concentration of male mallards fed the selenium-only diet. Similar results were found with Japanese quail fed diets containing methylmercury and selenite (El-Begearmi et al. 1977, 1982).

High selenium concentrations can affect the health of mature birds. At Kesterson Reservoir, chronic selenium toxicosis caused American coots (*Fulica americana*) to lose mass and feathers (Ohlendorf et al. 1990). American kestrels (*Falco sparverius*) fed a diet containing 12 µg Se/g of food had a lower ratio of fat and a higher ratio of lean mass to total body mass (Yamamoto and Santolo 2000). Adult mallards maintained on a diet enriched with 20 µg Se/g of food had lesions in their liver and integument. Mallards on a diet of 40 µg/g lost weight and exhibited abnormalities such as feather loss, loss of nails, and beak necrosis (Albers et al. 1996, O'Toole and Raisbeck 1998). We noted none of these abnormalities among the eared grebes we collected from the GSL, and their body mass was usually not related to either selenium or mercury concentrations. Furthermore, when there was a statistically significant correlation between body mass and selenium or mercury concentrations, the relationship was positive. Liver mass, pancreas mass, and spleen mass were not correlated with either mercury or selenium concentrations.

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Table 1. Effect of collection site, collection date, sex of bird, and its age on the mean (± SE) concentration of selenium (ug/g dry weight); concentration of mercury (ug/g dry weight); and mass of body, liver, pancreas, and spleen (g wet weight) of eared grebes collected during 2006 on the Great Salt Lake, Utah.

	Collection sites		Collection dates		Sex		Age	
	Antelope	Stansbury	September	November	Male	Female	Juvenile	Adult
Se – blood	16.8 ± 2.3	25.4 ± 3.0	18.5 ± 2.5	23.3 ± 2.9	21.8 ± 3.0	19.7 ± 2.4	16.1 ± 2.3	25.2 ± 2.8
Se—liver	8.6 ± 0.5	15.2 ± 1.4	9.4 ± 0.7	14.5 ± 1.4	12.0 ± 1.2	11.8 ± 1.2	8.5 ± 0.7	15.8 ± 1.3
Hg—blood	4.3 ± 0.5	10.1 ± 1.0	5.6 ± 0.5	8.4 ± 1.2	7.1 ± 1.0	6.8 ± 0.9	5.5 ± 0.8	8.4 ± 1.0
Hg—liver	--	12.9 ± 1.7	10.1 ± 2.6	15.6 ± 1.9	14.1 ± 2.4	10.6 ± 1.7	13.1 ± 3.6	12.7 ± 1.8
Mass—body	480 ± 21	491 ± 25	381 ± 14	591 ± 11	521 ± 23	440 ± 20	431 ± 24	549 ± 16
Mass—liver	17.9 ± 1.2	17.0 ± 0.9	14.1 ± 0.8	20.8 ± 0.8	18.7 ± 1.0	15.7 ± 0.9	15.5 ± 1.1	19.8 ± 0.7
Mass—pancreas	0.25 ± 0.05	0.22 ± 0.05	0.15 ± 0.03	0.36 ± 0.07	0.24 ± 0.03	0.24 ± 0.09	0.25 ± 0.06	0.22 ± 0.05
Mass—spleen	0.20 ± 0.02	0.19 ± 0.01	0.19 ± 0.01	0.21 ± 0.02	0.21 ± 0.02	0.18 ± 0.01	0.19 ± 0.02	0.22 ± 0.02

Table 2. Mean (± SE) concentration of selenium (ug/g dry weight), concentration of mercury, (ug/g dry weight), and body mass (g wet weight) of eared grebes collected during November 2006 on the Great Salt Lake, Utah.

	Juveniles		Adults	
	Males	Females	Males	Females
Se – blood	17.8 ± 3.5 (*n* = 5)	14.6 ± 5.1 (*n* = 4)	29.2 ± 6.6 (*n* = 7)	27.1 ± 4.7 (*n* = 5)
Se—liver	8.4 ± 1.2 (*n* = 9)	12.7 ± 5.8 (*n* = 3)	17.9 ± 2.4 (*n* = 12)	17.6 ± 2.4 (*n* = 6)
Hg—blood	6.2 ± 2.3 (*n* = 5)	4.0 ± 2.0 (*n* = 4)	10.4 ± 2.3 (*n* = 7)	11.6 ± 1.8 (*n* = 5)
Hg—liver	--	--	15.7 ± 3.1 (*n* = 6)	14.7 ± 1.6 (*n* = 3)
Mass—body	593 ± 20 (*n* = 9)	569 ± 61 (*n* = 3)	623 ± 13 (*n* = 12)	539 ± 17 (*n* = 6)

Table 3. ANOVA tables for the effect of collection site, collection time, sex of bird, and age of bird on selenium and mercury concentrations (number of birds used for a comparison is one more than the two different degrees of freedom).

Term	Selenium (blood)			Selenium (liver)			Mercury (blood)		
	F	df	*P*	*F*	df	*P*	*F*	df	*P*
Site	5.91	1,27	0.02	53.65	1,44	0.0001	63.16	1,27	0.0001
Date	1.98	1,27	0.17	23.21	1,44	0.0001	19.93	1,27	0.0001
Site X Date	8.67	1,27	0.007	83.26	1,44	0.0001	34.09	1,27	0.0001
Sex	0.75	1,27	0.39	0.97	1,44	0.33	1.76	1,27	0.20
Site X Sex	0.01	1,27	0.94	2.80	1,44	0.10	1.63	1,27	0.21
Date X Sex	0.35	1,27	0.55	0.09	1,44	0.77	3.50	1,27	0.07
Site X Date X Sex	0.67	1,27	0.42	0.28	1,44	0.60	1.70	1,27	0.20
Age	1.80	1,27	0.19	7.49	1,44	0.009	0.84	1,27	0.36
Site X Age	0.11	1,27	0.73	1.41	1,44	0.24	0.11	1,27	0.73
Date X Age	0.06	1,27	0.81	5.54	1,44	0.02	1.92	1,27	0.17
Site X Date X Age	1.35	1,27	0.26	1.58	1,44	0.22	0.64	1,27	0.42
Sex X Age	2.64	1,27	0.11	0.10	1,44	0.76	5.84	1,27	0.02
Site X Sex X Age	0.05	1,27	0.83	1.15	1,44	0.29	0.05	1,27	0.83
Date X Sex X Age	3.05	1,27	0.09	6.61	1,44	0.01	0.00	1,27	0.94
Site X Date X Sex X Age	0.36	1,27	0.55	15.02	1,44	0.0004	0.72	1,27	0.40

Table 4. Regression analyses among selenium and mercury concentrations in the blood and liver and mass of body, liver, pancreas, and spleen using all eared grebes (males and females, juveniles and adults) collected during 2006 on the Great Salt Lake, Utah (number of birds used for a comparison is one more than the two different degrees of freedom).

Variable 1	Variable 2	r^2	*F*	df	*P*
Se (blood)	Body mass	0.09	4.03	1,40	0.05
	Liver mass	0.002	0.07	1,40	0.80
	Pancreas mass	0.003	0.06	1,18	0.82
	Spleen mass	0.06	1.82	1,27	0.19
	Se (blood)	--	--	--	--
	Se (liver)	0.49	37.98	1,40	<0.001
	Hg (blood)	0.49	38.78	1,41	<0.001
	Hg (liver)	0.47	12.46	1,14	0.003
Se (liver)	Body mass	0.32	27.72	1,58	<0.001
	Liver mass	0.06	3.41	1,58	0.07
	Pancreas mass	0.10	2.63	1,23	0.12
	Spleen mass	0.02	0.75	1,38	0.39
	Se (blood)	see above			
	Se (liver)	--	--	--	--
	Hg (blood)	0.54	47.12	1,40	<0.001
	Hg (liver)	0.22	5.12	1,18	0.04
Hg (blood)	Body mass	0.20	10.06	1,40	0.003
	Liver mass	0.04	1.64	1,40	0.21
	Pancreas mass	0.08	1.49	1,18	0.24
	Spleen mass	0.003	0.08	1,27	0.78
	Se (blood)	see above			

	Se (liver)	see above				
	Hg (blood)	--	--	--	--	
	Hg (liver)	0.59	20.14	1,14	<0.001	
Hg (liver)	Body mass	0.08	1.62	1,18	0.22	
	Liver mass	0.01	0.18	1,18	0.68	
	Pancreas mass		0.99	92.26	1,3	0.07
	Spleen mass	0.23	1.87	1,6	0.22	
	Se (blood)	see above				
	Se (liver)	see above				
	Hg (blood)	see above				
	Hg (liver)	__	__	__	__	

Table 5. Regression analyses between selenium concentrations in the blood and liver, mercury concentrations in the blood and avian mass using male eared grebes collected during November 2006 on the Great Salt Lake, Utah (number of birds used for a comparison is one more than the two different degrees of freedom).

		Juvenile males				Adult males			
Variable 1	Variable 2	r^2	*F*	df	*P*	r^2	*F*	df	*P*
Se (blood)	Body mass	0.32	1.40	1,3	0.08	0.28	1.92	1,5	0.23
	Se (blood)	--	--	--	--	--	--	--	--
	Se (liver)	0.98	162.72	1,3	0.001	0.92	56.58	1,5	0.001
	Hg (blood)	0.96	78.27	1,3	0.003	0.65	9.58	1,5	0.03
	Hg (liver)	insufficient data				0.48	1.84	1,2	0.31
Se (liver)	Body mass	0.31	3.12	1,7	0.12	0.36	5.74	1,10	0.04
	Se (blood)	see above					see above		
	Se (liver)	--	--	--	--	--	--	--	--
	Hg (blood)	0.98	155.27	1,3	0.001	0.82	24.12	1,5	0.004
	Hg (liver)	insufficient data				0.53	4.55	1,4	0.10
Hg (blood)	Body mass	0.42	2.19	1,3	0.23	0.46	4.27	1,5	0.09
	Se (blood)	see above					see above		
	Se (liver)	see above					see above		
	Hg (blood)	--	--	--	--	--	--	--	--
	Hg (liver)	insufficient data				0.64	3.67	1,2	0.19
Hg (liver)	Body mass	insufficient data				0.36	2.21	1,4	0.21
	Se (blood)	insufficient data					see above		
	Se (liver)	insufficient data					see above		
	Hg (blood)	insufficient data					see above		
	Hg (liver)	--	--	--	--	--	--	--	--

Table 6. Regression analyses between selenium concentrations in the blood and liver, mercury concentrations in the blood and avian mass using female eared grebes collected during November 2006 on the Great Salt Lake, Utah (number of birds used for a comparison is one more than the two different degrees of freedom).

		Juvenile females					Adult females		
Variable 1	Variable 2	r^2	*F*	df	*P*	r^2	*F*	df	*P*
Se (blood)	Body mass	0.96	25.42	1,1	0.12	0.15	0.54	1,3	0.51
	Se (blood)	--	--	--	--	--	--	--	--
	Se (liver)	1.0	7930.0	1,1	0.007	0.68	6.44	1,3	0.09
	Hg (blood)	0.86	12.72	1,2	0.07	0.41	2.06	1,3	0.25
	Hg (liver)	insufficient data				0.47	0.90	1,1	0.52
Se (liver)	Body mass	0.96	22.67	1,1	0.13	0.46	3.45	1,4	0.14
	Se (blood)	see above					see above		
	Se (liver)	--	--	--	--	--	--	--	--
	Hg (blood)	0.95	20.1	1,1	0.14	0.80	11.94	1,3	0.04
	Hg (liver)	insufficient data				0.00	0.00	1,1	0.99
Hg (blood)	Body mass	1.0	6521.0	1,1	0.008	0.22	0.87	1,3	0.42
	Se (blood)	see above				see above			
	Se (liver)	see above				see above			
	Hg (blood)	--	--	--	--	--	--	--	--
	Hg (liver)	insufficient data				0.91	10.7	1,1	0.19
Hg (liver)	Body mass	insufficient data				0.31	0.45	1,1	0.63
	Se (blood)	insufficient data					see above		
	Se (liver)	insufficient data					see above		
	Hg (blood)	insufficient data					see above		
	Hg (liver)	--	--	--	--	--	--	--	--

Appendix 1. Data on individual eared grebes collected during 2006 on the Great Salt Lake including food in their esophagus (bs = adult brine shrimp, bf = adult brine flies, bfl = brine fly larva, c = hundreds of cysts.

Sample	Location date	Sex	Age	Mass Body	Liver	Gizzard	Pancreas	Spleen	Selenium		Mercury		Food
		1= male 2= female	1= juvenile 2 = adult						Blood	Liver	Blood	Liver	
EG-A1	Antelope 9/11/06	1	1	293	4.4	--	--	0.098	7.1	5.9	0.55	-	
EG-A2	Antelope 9/11/06	2	1	342	12.5	--	0.096	0.200	12.8	8.4	6.6	-	
EG-A3	Antelope 9/11/06	2	2	455	18.9	30.5	0.135	--	31.5	11.2	4.8	-	
EG-A4	Antelope 9/11/06	2	2	478	23.0	31.4	--	0.227	20.1	10.7	5.81	-	
EG-A5	Antelope 9/11/06	1	1	357	13.8	24.0	0.116	0.140	16	9.8	4.9	-	12 bs, 11 bf, c
EG-A6	Antelope 9/11/06	2	2	504	18.8	28.3	--	0.187	32.8	16.8	6.35	-	
EG-A7	Antelope 9/11/06	1	2	424	14.1	28.4	0.264	0.307	36.3	15.2	3.7	-	
EG-A8	Antelope 9/11/06	1	1	285	9.5	18.0	--	0.122	45.9	5	8.6	-	
EG-A9	Antelope 9/11/06	1	2	582	18.0	29.1	0.127	0.368	6.8	16	3.2	-	104 bs, 6 bf, c
EG-A10	Antelope 9/11/06	2	2	444	19.1	27.7	0.032	0.183	21.3	11.4	8.19	-	19 bs, 1bf, c
EG-A11	Antelope 9/11/06	1	1	388	17.9	30.8	0.287	0.329	9.7	6.9	7.78	-	15 bs, 8 bf
EG-A12	Antelope 9/11/06	2	1	366	11.5	28.4	0.082	0.187	0.3	11.9	0.09	-	36 bs, 6 bf
EG-A13	Antelope 9/11/06	2	1	394	14.0	30.1	0.081	0.112	-	8.6	-	-	20 bf
EG-A14	Antelope 9/11/06	2	1	245	9.0	13.3	0.025	0.085	-	5.9	-	-	3 bs, 2 bf
EG-A15	Antelope 9/11/06	2	1	318	7.0	24.2	--	--	-	7.2	-	-	
EG-A51	Antelope 11/10/06	1	1	651	21.6	29.3	0.119	0.240	13	7.1	3.8	-	100% bs
EG-A52	Antelope 11/10/06	1	2	633	23.0	33.2	0.369	0.213	17.8	7	4.2	-	100% bs
EG-A53	Antelope 11/10/06	1	2	542	17.7	31.6	0.347	0.191	15.2	7.5	3.2	-	100% bs
EG-A54	Antelope 11/10/06	1	1	604	33.2	34.2	--	0.147	14.2	6.4	4.3		
EG-A55	Antelope 11/10/06	2	1	490	14.0	25.8	0.581	0.139	15.9	7.1	2.6	-	
EG-A56	Antelope 11/10/06	1	1	550	20.7	33.9	0.405	0.247	16.1	7.3	3.3	-	

EG-A57	Antelope 11/10/06	1 1	520 17.3 23.5 -- 0.432	-	6.9	-	-	100% bs
EG-A58	Antelope 11/10/06	1 1	580 24.3 30.0 0.397 0.319	-	7.8	-	-	100% bs
EG-A-59	Antelope 11/10/06	1 1	565 27.2 37.6 0.085 0.168	-	7.2	-	-	100% bs
EG-A60	Antelope 11/10/06	1 2	607 26.6 33.7 0.358 0.200	10.3	8.7	4.4	-	
EG-A61	Antelope 11/10/06	2 2	500 18.6 27.6 -- 0.189	12.8	7.1	4.7	-	100% bs
EG-A62	Antelope 11/10/06	1 1	673 20.4 31.4 -- --	-	8.2	-	-	
EG-A63	Antelope11/10/06	2 1	529 18.6 29.0 0.902 0.147	15.8	6.7	4	-	100% bs
EG-A64	Antelope 11/10/06	1 1	520 14.3 18.4 0.335 0.200	14.2	6.8	4	-	100% bs
EG-A65	Antelope 11/10/06	1 2	587 28.0 25.8 0.041 0.140	-	7	-	-	100% bs
EG-A66	Antelope 11/10/06	2 1	---- ---- ---- -- --	1.1	-	0.05	-	
EG-Hat1	Stansbury 9/13/06	2 1	342 13.1 26.5 0.211 0.267	6.8	5.5	7	7.06	65 bs, c
EG-Hat2	Stansbury 9/13/06	2 1	378 16.7 27.6 -- 0.214	13.7	7.1	3.5	-	42 bs, c
EG-Hat3	Stansbury 9/1/3/06	1 1	384 15.3 32.7 0.078 0.110	32.7	12.7	8.13	10.2	
EG-Hat4	Stansbury 9/13/06	1 2	403 16.0 30.0 -- 0.257	9.1	6.2	4.8	4.6	
EG-Hat5	Stansbury 9/13/06	2 2	397 10.3 18.4 -- --	25.2	9.7	5.83	7.45	1 bs
EG-Hat6	Stansbury 9/13/06	1 2	499 21.7 33.6 0.337 0.160	7.7	5.6	4.9	5	15 bs
EG-Hat7	Stansbury 9/13/06	2 1	401 18.1 34.7 0.235 0.260	10.4	7.2	8.62	-	16 bs, 1 bf
EG-Hat8	Stansbury 9/13/06	1 1	363 17.4 35.6 -- 0.188	22.4	10.5	6.42	7.23	
EG-Hat-9	Stansbury 9/13/06	2 1	336 10.6 18.4 -- 0.130	-	6	-	4.5	
EG-Hat10	Stansbury 9/13/06	1 1	308 9.8 14.6 -- --	13.5	8	6.35	12.3	
EG-Hat-11	Stansbury 9/13/06	1 1	336 11 1 23.8 -- 0.170	-	8.9	-	-	26 bs, 1 bfl, c
EG-Hat-12	Stansbury 9/13/06	2 1	324 15.6 31.4 -- 0.212	-	7.9	-	-	1 bfl
EG-Hat13	Stansbury 9/13/06	2 2	469 19.2 28.7 -- 0.176	25.6	20.3	6.66	10.5	55 bs, 1 bf
EG-Hat14	Stansbury 9/13/06	2 1	316 8.2 19.5 0.312 0.192	-	6	-	-	6 bs, 1 bf
EG-Hat16	Stansbury 9/13/06	1 1	297 8.5 14.4 -- 0.108	-	8.8	-	32.2	5 bs
EG-Hat71	Stansbury 11/22/06	1 2	622 18.6 24.8 -- --	55.3	28.4	14	17	100% bs
EG-Hat72	Stansbury 11/22/06	1 2	717 16.8 25.7 -- --	50	27.4	18	28	
EG-Hat73	Stansbury 11/22/06	1 1	675 21.8 32.6 -- --	31.7	17.8	15.4	17.9	
EG-Hat74	Stansbury 11/22/06	1 2	598 26.0 27.9 -- --	31.7	17.8	14.6	5.87	100% bs

EG-Hat75	Stansbury 11/22/06	2 2	562 20.6 22.8 -- --	26	17.2	11.5	13.1	100% bs
EG-Hat76	Stansbury 11/22/06	2 2	600 23.4 27.3 -- --	37.8	24.2	12.7	13.1	100% bs
EG-Hat77	Stansbury 11/22/06	2 2	559 19.6 21.2 -- --	22.2	20.6	15.5	18	100% bs
EG-Hat78	Stansbury 11/22/06	1 2	660 18.6 30.4 -- --	24	18.1	14.4	11.6	100% bs
EG-Hat79	Stansbury 11/22/06	1 2	655 20.2 30.5 -- --	-	24.9	-	12.7	100% bs
EG-Hat80	Stansbury 11/22/06	1 2	591 22.4 25.6 -- --	-	22.5	-	18.8	100% bs
EG-Hat81	Stansbury 11/22/06	2 2	500 12.4 24.0 -- --	36.9	19.3	13.5	-	100% bs
EG-Hat82	Stansbury 11/22/06	2 2	513 20.2 24.8 -- --	-	17.4	-	-	100% bs
EG-Hat83	Stansbury11/22/06	1 2	604 21.3 22.7 -- --	-	18.8	-	-	100% bs
EG-Hat84	Stansbury 11/22/06	1 2	660 20.6 26.2 -- --	-	26.3	-	-	100% bs
EG-Hat85	Stansbury 11/22/06	2 1	688 17.4 28.9 -- --	25.7	24.2	9.27	-	100% bs